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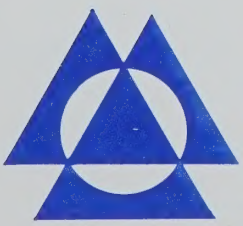
BIOCIDES AND BIRDS:
A Survey of the Effects of Biocides on Birds

— A Staff Report —

R. E. ROGERS



Alberta

ENVIRONMENT CONSERVATION AUTHORITY
OCTOBER, 1976

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ENVIRONMENT CONSERVATION AUTHORITY

MEMORANDUM

FROM: W.A. Flook DATE: October 26, 1976

TO: Dr. W.R. Trost

Subject: STAFF REPORT - BIOCIDES AND BIRDS: A SURVEY OF THE EFFECTS OF BIOCIDES ON BIRDS

Following certain submissions which had drawn the attention of the Authority to the adverse effects of biocides on birds during its public hearings on pesticides, you had requested a more complete report on the subject.

In response, Mr. Robert Rogers of the Authority's Research Staff has conducted a review of such factual information as could be obtained on the subject and produced the present staff report.

I have reviewed Mr. Rogers' report and now have pleasure in submitting it to you for the Authority's consideration.

W.A. Flook

WAF/jp
attach.

FOREWORD

During its public hearings on the Use of Pesticides and Herbicides in Alberta the Authority received submissions particularly in urban centres, directing attention to the ill-effects of pesticides on birds. They wished to draw attention to the accidental destruction of bird populations when chemicals were used for other purposes .

The Authority was sufficiently concerned to hold a special supplementary hearing devoted to this subject alone, and was told of the reduction or disappearance of bird colonies which had been established through many years of careful nurture by bird lovers within the cities. Those making submissions attributed loss of birds to the accidental avicidal effect of pesticides directed at other targets.

To further illuminate the situation, the Authority commissioned the present staff report and hopes that it will provide a basis of factual information to assist the public in their understanding and assessment of the dangers currently being presented to birds by the use of biocides.

Dr. W.R. Trost
Chairman
Environment Conservation Authority

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1. Introduction

1. INTRODUCTION

Biocides have been liberally used for a long time as a major tool in reducing the effects of various plant and animal species considered to be in some way detrimental to Man. These chemicals have undergone widespread application in fields, forests and marshlands, thereby introducing them into virtually all parts of the environment.

Industrial waste disposal and leakage, application spillage and drift and chemical volatility are just a few factors contributing to the overall distribution of these chemicals and their breakdown products in the environment.

It is becoming clear that the utilization of biocides to control various species can produce biological effects greater than those for which the chemical was intended. The complexity of this situation becomes apparent if one considers the inter-relationships of biocides in the ecosystem, where chemical distribution and effects are closely interwoven with energy flow and nutrient cycles (figure 1). This means that the effects of biocide application can be manifest in many ways through the interaction with other factors in the ecosystem. Consequently, these effects are rarely mutually exclusive. As a result of this, changes in animal populations can arise from primary or secondary biological effects such as reduced reproductive potential and survival of the young, increased susceptibility to predation and diseases, selection for biocide resistance or altered behavioral patterns.

Although considerable research is needed to elucidate more fully the potential hazards to wildlife associated with the use of biocides, it seems unrealistic that a moratorium on their use should be invoked, particularly at a time when maximum food production is essential to the population of the world. It is realistic though that all available knowledge on various biocides be used to determine whether control by biocides is needed, and if so, which particular biocide, and at what concentration. Such a situation is realistic in balancing the beneficial effects of a chemical with its potential hazards, thereby enabling the necessary precautions to be taken with respect to the method of chemical application, the areal extent of application, the season, time and quantity of biocide that can be expected to produce only the minimum hazard to non-target wildlife and Man.

Among the most documented cases of the effects of biocide use in the environment relates to the uptake, distribution, accumulation and effects of these chemicals in avian species. Over the past several years

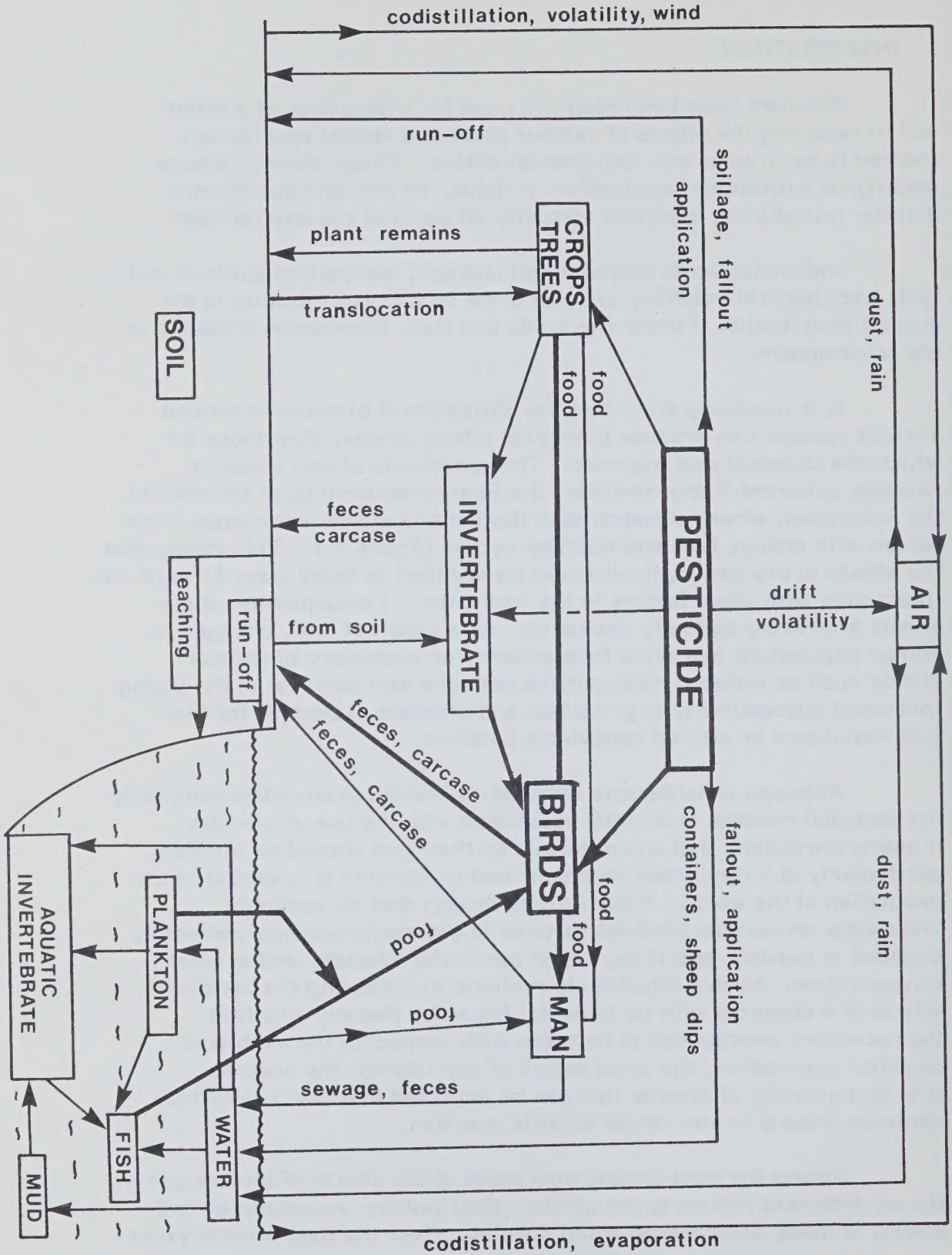


FIGURE 1

PESTICIDE CYCLING IN THE ENVIRONMENT

numerous reports have been published linking bird mortality to the application of biocides. These reports have not always been able to be substantiated but have, nevertheless, focussed attention on a potentially serious problem. Even more recently, the amount of research undertaken to examine this problem has been magnified several-fold. The amount of literature now being published pertaining to biocides and birds is voluminous.

In recent public hearings held by the Environment Conservation Authority on The Use of Pesticides and Herbicides in Alberta, the problem of detrimental effects of biocides on non-target organisms such as birds was a major concern. Since birds are ubiquitous in our environment and highly mobile, they are in a prime position to be exposed to the wide array of biocides presently used by our society. This situation is not a desirable one, unless, as in the case of nuisance birds such as magpies, pigeons or blackbirds, population control is the ultimate objective. Birds are beneficial to Man. They provide him with such things as insect and rodent control as well as considerable aesthetic benefits.

The Environment Conservation Authority, in recognizing the problems created to birds by biocides, commissioned the present staff report to elucidate the biocide-bird situation in more detail. In this respect, an attempt has been made to broadly survey the situation, bearing in mind that a comprehensive review of the effects of the multitude of chemicals presently being used would be a massive undertaking and must, therefore, remain beyond the scope of this report. The report is intended to provide factual information on the major areas of concern in the hope that an overall view of the situation is valuable in promoting an understanding of the potential hazards that biocides present to birds in our environment.

2. Terminology

2. TERMINOLOGY

In this report the term **"biocide"** is used in a general sense to refer to any man-made chemical formulation that repels, suppresses or causes death in any living organism. This term encompasses the more specific terms **"herbicide"** which refer to chemicals formulated to kill or control weeds and **"pesticide"** which refers to any substance or mixture of substances used in preventing, destroying, repelling or mitigating any insect, nematode, rodent, predatory animal, bird, bacteria, fungus or other form of animal life.

Both herbicides and pesticides can be identified by the biological "target organism" that they are intended to control. Therefore, **"avicides"** can be considered to be pesticides formulated explicitly to repel, suppress, control or kill birds.

Since many biocides can also exert deleterious side effects on birds as "non-target organisms," these chemicals may be considered to possess avicidal properties. As such, they may be referred to as "accidental avicides." Other terms used in this report are defined in the glossary.

GLOSSARY OF TERMS

Acute oral toxicity (LD_{50}):	The dosage of biocide, when given orally, that will produce death in 50 percent of test organisms.
Acute exposure (LC_{50}, LC_{95},):	That concentration of biocide that produces death in 50 percent or 95 percent of test organisms when applied to the skin, eyes or feet.
Biological half-life:	The time required for one-half of the amount of a substance in a living organism to be eliminated, whether by excretion, metabolic decomposition, or other natural process.
Biological magnification:	Buildup in concentration of some substance, such as DDT, in successively higher trophic levels of the food chain or web.

Chronic toxicity:	The long-lasting and severe effects that a substance exerts on a living organism without causing its immediate death.
Equine encephalitis:	Also called "North American sleeping sickness." Inflammation of the brain resulting from the transmission of viruses from horses to man by mosquitos.
Filariasis:	Disease resulting from the introduction of parasitic worms into the blood by certain flies and mosquitos.
In vitro:	By derivation means "in glass." Applied to biological processes it refers to processes experimentally made to occur in isolation from the whole organism (e.g., in test tubes).
In vivo:	Within the living organism.
Non-target species:	Those plants, insects or animals that in the specific situation are not considered as pests and, therefore, should, if possible, be protected from the biocide.
Ovary:	Female organ that produces eggs (ova) to be fertilized and the sex hormones estrogen and progesterone.
Residue:	A deposit that remains in, or on, a plant or animal following the application of a biocide.
Sublethal accumulation:	The accumulation of biocide in the tissues of a living organism at a level which is below the level required to kill the organism outright.

Synergism:	The combined activity of substances (e.g., drugs, hormones, biocides) which separately influence a certain process in the same direction, such that the effect produced is greater than the sum of the effects of each substance alone.
Trophic level:	Level where energy in the form of food is transferred from one organism to another.
Toxicity:	The degree to which a substance is injurious to a plant or animal.
Weed:	A plant that grows where man does not want it to grow.

3. Chemical Classification of Biocides

3. CHEMICAL CLASSIFICATION OF BIOCIDES

The chemical structures of biocides cover a broad spectrum. The groups most commonly referred to are the organochlorines (including PCB's), organophosphates, carbamates and inorganics.

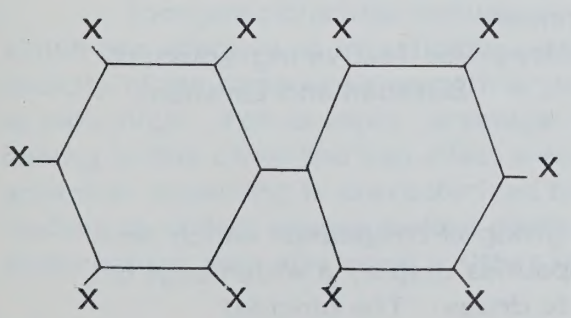
ORGANOCHLORINE COMPOUNDS:

These compounds are chlorinated hydrocarbons that differ widely in chemical structure and activity. Their usefulness to Man lies in their effectiveness for insect control. Although their cost is relatively low, making them attractive for large-scale operations, they are generally "persistent" compounds that remain for a considerable period of time on treated plants and soils and are readily stored in animal fat.

The modes of action of various members of this class are often so divergent as to suggest quite different methods of activity. In general, however, the site of physiological action in the insect is the central nervous system. Here they produce a variety of responses from increased sensitivity to severe tremors, tonic contractions and convulsions.* Some common examples of this class of chemicals are

aldrin	endrin
BHC	endosulfan (thiodan)
chlordane	heptachlor
DDT	lindane
Dicofol	methoxychlor
dieldrin	PCB's

Another group of organochlorines that have recently surfaced as potent toxicants are the polychlorinated biphenyls or PCB's. Within this group a mixture of different structures exist with the basic structure:



"X" indicates the position to which a chlorine atom may attach.

* For a review of biological and environmental aspects, see Brooks, 1974.

PCB's come under the American trade name Aroclor or the Japanese trade name Kamechlor.

The physical properties of PCB's have been described by Hutzinger *et al.*, (1974) but, in brief, they are chemically inert, resist alkalies, acids and other corrosive chemicals, have low volatility, are very stable and relatively insoluble in water.

The stability of PCB's makes them "persistent" in soil, water, plants and animals. As such, they have been found to accumulate at all levels of the food chain (Peakall, 1975a). The effects these chemicals exert at these levels has been reviewed by Peakall (1975a).

ORGANOPHOSPHATE COMPOUNDS:

Organophosphates are a large group of phosphate-substituted hydrocarbons. Toxicity of these compounds ranges from some of the most toxic to some of the safest biocides in use. Unlike the chlorinated hydrocarbons, these compounds are much less persistent. They are rapidly broken down in soil, plants and animals. Because of this, there is less danger of long-term residue contamination. However, prolonged exposure to small amounts of these chemicals can lead to poisoning.

Some organophosphates are plant systemics while others are animal systemics used to control endo and ectoparasitic infections of livestock. The general mode of action of these compounds and their metabolites is as potent inhibitors of the insect neural enzyme cholinesterase. This action impedes the transmission of nerve impulses to glands and muscles, resulting in muscular weakness and tremors, which ultimately leads to the death of the organism.

Common examples or organophosphates are

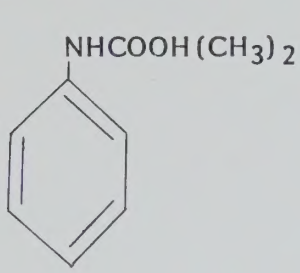
abate
dichlorvos
dimethoate
malathion (Cythion)
parathion
fenthion
chlorpyrifos (active ingredient of Dursban and Lorsban)

CARBAMATES:

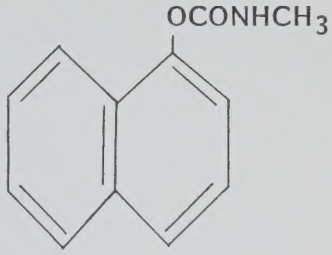
Carbamates are a relatively new group of compounds which are derivatives of carbamic acid. These compounds display a wide range of biological activity ranging from biocides to drugs. The biocidal

carbamates fall broadly into two classes of herbicides and pesticides. The herbicidal compounds are exemplified by propham (N-phenyl-isopropyl carbamate), whereas the insecticides are exemplified by carbaryl, perhaps the best known compound of this type.

The chemical stuctures of these compounds are as follows:



Propham



Carbaryl

All insecticidal carbamates are inhibitors of cholinesterase, and consequently are similar in action to the organophosphates (O'Brien, 1967). Carbamates are, however, more selective in their toxicity to insects than either the organochlorines or - phosphates, and therefore, have a more limited applicability.

In terms of the metabloic reactions undergone *in vivo,* the number and types of reactions is limited to oxidation, reduction, hydrolysis and conjugation (Ryan, 1971). Metabolism of these compounds is generally rapid and in mammals shows little propensity for storage in tissues (Mitchell, 1966)*.

Other representative examples of carbamate compounds are carbofuran (Furadan) and methonyl (Lannate), Baygon, Landrin, Banonl, Mesurol, Zectran and Metacil.

INORGANICS:

Inorganic biocides include a wide range of inorganic compounds which are effective as insecticides, herbicides and fungicides. The toxicity of the compounds on non-target species varies from very low to very high. For example, arsenical compounds such as lead arsenate belong to this class and can affect a wide range of organisms. Acute arsenical poisoning is characterized by gastroenteritis and diarrhea leading to violent spasms before death. Kidney degeneration and vascular disturbances may also occur. Other inorganic biocides include copper

* For a more detailed review of carbamate metabolism, see Ryan, 1971.

sulfate, sodium fluoraluminate, sodium fluoracetate (compound 1080), cyrolite (sodium aluminum fluoride), mercuric chloride and sulphur and calcium hypochlorite.

4. Occurrence and Distribution of Biocides in Birds

4. OCCURRENCE AND DISTRIBUTION OF BIOCIDES IN BIRDS

4.1 UPTAKE OF BIOCIDES BY BIRDS

Biocides may be taken up by birds in a number of direct or indirect ways, and depending on the mode of uptake can subsequently exert a variety of effects ranging from immediate death to sublethal accumulation in bird tissues.

4.1.1 Air

Since many biocides are volatile to a certain degree, birds occupying or passing through areas that have been exposed to these chemicals may take up the chemical via the normal breathing process. Chemicals inhaled by birds are generally in the form of vapours or aerosols (i.e., small liquid droplets or solid particles) - Edwards (1970, 1973), Fowle (1972). In the case of solid particles, dust is also an important contributor of inhaled pesticides since many pesticides (i.e., chlorinated hydrocarbons) have a high affinity for dust particles. Highly sensitive analytical techniques have borne out this observation (Cohen and Pinkerton 1966; Alford, 1975).

Once inhaled, the chemical may pass across the respiratory membrane and enter the bloodstream where it can then be transported throughout the body, to be taken up by other tissues (e.g., brain, liver, kidney, nerve, etc.) or it may remain in the respiratory tissues (e.g., lung, trachae, syrinx, etc.), or do both.

The degree to which chemical inhalation occurs has been correlated to the concentration of biocide in the air at any given time, uptake generally increasing with increasing biocide concentration (Fowle, 1972). The atmospheric concentration of a biocide may, in turn, be affected by such variables as temperature, wind flow patterns, topography and vegetation types, biocide droplet size, the amount of dust and other wind-blown materials (e.g., micro-organisms, spores) to which these chemicals adhere, rate of natural diffusion in the atmosphere and rate of evaporation of biocides from contaminated plant, soil or water surfaces.

From the foregoing, it should be clear that the hazard airborne biocides create for birds is difficult and complex to define. Nevertheless, the hazard does exist and should be recognized and further studied to elucidate more fully the toxicological effects of this mode of biocide uptake on avian species.

Perhaps one of the more important aspects of this situation concerns atmospheric transport of biocides. It is now known that some chemicals after application are transported through the atmosphere to areas far removed from the original point of application (Hurtig, 1972). For example, measurement of fenitrothion* in the air of towns in New Brunswick revealed high concentrations detectable as far as 40 miles from the original treated area (Yule *et al.*, 1971). The significance of this finding becomes even more pronounced by reports that biocides have been found in "clean" polar and high mountain air samples (Alford, 1975). Consequently, the hazard presented to birds, as well as other forms of wildlife, by airborne biocides is indeed real and widespread. Therefore, when considering the uptake of these chemicals by birds, it is necessary to consider two important factors. First, since biocides can be distributed over large areas by atmospheric conditions, it is likely that more individual birds and bird species are exposed to the biocide than expected. Secondly, the highly mobile nature of many bird species means that they can be exposed to a variety of different biocides and biocide concentrations during their movements. This can, in turn, lead to the uptake of more than one chemical which may or may not act synergistically to produce adverse affects in the birds. Liang and Lichtenstein (1974) have already demonstrated synergistic effects of DDT and parathion in the fruit fly, *Drosophila melanogaster*, by the herbicide atrazine. Extrapolation of this phenomenon to other animal species is not unrealistic.

One redeeming point in this situation is that many pesticides are degraded by ultraviolet rays in sunlight so it is possible that residues carried in the upper air may break down during atmospheric transport, thereby mitigating the hazard to birds. However, much more information about this subject is necessary, particularly information related to the detection and effects of the breakdown products.

4.1.2 Water

There are many routes by which biocides may contaminate natural waters (e.g., ponds, lakes, rivers). One of the most direct and recurrent ways is from aerial sprays applied to control pests such as mosquitos, black flies and midges, or from aerial treatments used to control forest or agricultural pests. Other factors contributing to water contamination include surface run-off from contaminated plants and soil, leaching from contaminated soil to groundwater, discharge with sewage and industrial effluents, and removal from the atmosphere in rain.

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* Used to control spruce budworm infestations in forests.

Nicholson (1967) reports that the two principal sources of contamination are "runoff from agricultural land and discharge of industrial wastes, either from industries that manufacture or formulate pesticides, or from those that use these compounds in their manufacturing processes, e.g., moth-proofing chemicals." Edwards (1970) also cites careless applications of insecticides and disposal or washing of insecticide containers as a source of residues in natural waters.

Advanced monitoring techniques (Alford, 1975) indicate that all major classes of biocides have been detected in North American waters. However, the hazard created for wildlife by these chemicals seems to vary. Organochlorine pesticides, for example, have a low solubility in water and are not usually in solution. They are normally carried to water adhered to particulate matter. In this case, the pesticides have been found to sediment out fairly rapidly into the bottom mud and vegetation (Bridges *et al.*, 1963; Green *et al.*, 1966). This means that the hazard to birds is generally not significant, unless, of course, birds ingest water particulates or aquatic organisms (e.g., fish, invertebrates) contaminated with these residues. Organophosphate pesticides, although more soluble than the organochlorines, are more rapidly degraded in the environment and therefore appear to present a lower toxicity hazard to wildlife such as birds. Two critical influences on toxicity are the volume of water contaminated by pesticides and the rate of water flow (Rudd, 1970). Shallow impounded waters create the greatest hazard due to biocide concentration whereas deeper or strongly flushed waters lessen the immediate impact and duration of the hazard.

Whatever the means by which natural waters become contaminated, it is clear that birds utilizing these waters will probably take up biocide residues and subsequently be exposed to their effects.

4.1.3 Food

Perhaps the most important route by which biocides enter birds is through their food, whether this is plant or animal. One of the fundamental principles to consider in this regard is "biological magnification" which refers to the progressive build-up in concentration of biocide residues in successively higher trophic levels of the food chain (Stickel, 1973; Cloud, 1975).

Biological magnification is important when considering the uptake of these chemicals by birds. The amount of biocide ingested depends to a large extent upon the trophic level in which the bird

feeds and the concentration of biocide residues in the plants or animals of that level (Dykstra, 1966; Stickel, 1973). Biological magnification of persistent biocides should not, however, be used as an absolute measure of the hazard to the bird since many new biocides degrade to end-products which also persist, yet are not as hazardous as the parent compound (Hurtig, 1972). Consequently, birds feeding on plants (e.g., seed-eaters) may ingest seeds contaminated unintentionally (i.e., through fall-out) or intentionally (e.g., mercury seed dressings to prevent fungal disease), while birds feeding on insects, worms, fish, other birds or mammals may ingest increasing quantities of sublethal residue doses that have accumulated in these food sources (Stickel, 1973) - see figure 2. A classic example of food-related effects on birds is the severe reduction in North American peregrine falcon populations resulting from the ingestion of food containing high levels of organochlorine pesticides (e.g., DDT) and their metabolites (e.g.,DDE, DDD) - Peakall *et al.*, 1975.

The hazard biocides present to different bird species then may or may not be serious, depending on the nature of the chemical and its by-products and the species of bird affected.

4.1.4 Other Sources

Biocides can also be taken up by birds by means other than through the diet. A series of experiments carried out on forest-dwelling species in New Brunswick from 1965 to 1968 (Fowle, 1965, 1972) demonstrated that debilitating or lethal doses of phosphamidon* could be absorbed through the feet. Exposure to perches, twigs, foliage and plastic surfaces sprayed with various concentrations of the chemical produced symptoms of poisoning which, in many cases, led to the death of the bird. It is important to remember that individual birds and bird species differ in their ability to absorb and metabolize chemicals. Therefore, not all birds in a biocide contaminated area can be expected to undergo the same response to a particular chemical. The response produced appears to be related to the kind of chemical, its concentration, the amount absorbed, the physiological condition of the bird, the natural resistance of the bird to the chemical and other extraneous factors (Brooks, 1974; Stickel, 1973).

Further evidence of biocide uptake following dermal contact is reported by Thomas and Medley (1971) who found that poultry dusted

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* Use to control spruce budworm infestations.

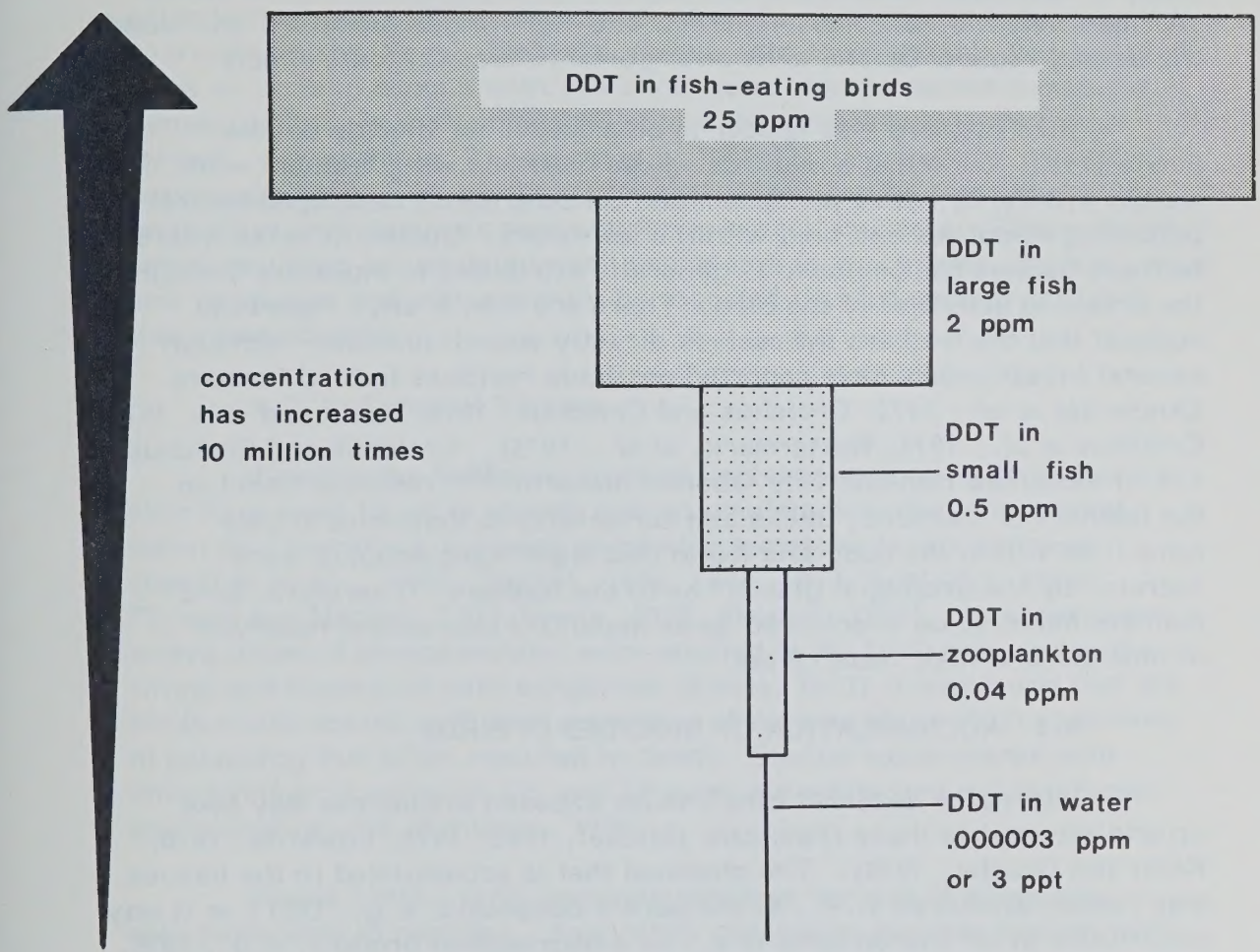

Figure 2. Concentration of DDT magnified approximately 10 million times in the food chain of Long Island Sound. Sources: (Miller, 1975; Woodwell *et al.*, 1967).

with powders containing dieldrin and DDT laid eggs containing these compounds. Schafer *et al.*, (1973) conducted a comparative dermal toxicity study of seventeen commercial and experimental pesticides on the *Quelea* (African weaverbird), house sparrow and red-winged blackbird and found the dermal route of uptake to be an important source of toxic effects.

Bird feathers also appear to be a source for biocide uptake. Fowle (1972) found that songbirds whose head and wing feathers were wetted with fairly heavy phosphamidon concentrations developed typical poisoning symptoms and died within a few hours. Uptake in cases where feathers become contaminated is generally attributed to ingestion through the preening activities of the bird. There are few, if any, reports to suggest that the feathers themselves directly absorb biocides although several investigators have reported pesticide residues in bird feathers (Anderlini *et al.*, 1972; Greichus and Greichus, 1974; Heath and Hill, 1974; Greichus *et al.*, 1975; Westermark, *et al.*, 1975). Greichus and Greichus (1974) examined radioactively labelled dieldrin-^{14}C residues found on the feathers of chickens, ducks and cormorants to determine if they came from within the body and found that significant amounts were secreted by the uropygial glands* on to the feathers. Therefore, bird feathers must not be overlooked as an important source and reservoir of biocides and their metabolites.

4.2 ACCUMULATION OF BIOCIDES IN BIRDS

Internal or external bird tissues exposed to biocides may take up and accumulate these chemicals (Stickel, 1968, 1973; Edwards, 1970; Keith and Gruchy, 1970). The chemical that is accumulated in the tissues may remain unaltered (i.e., as the parent compound; e.g., DDT) or it may accumulate in an altered form (i.e., as a degradation product; e.g., DDE, DDT, the latter chemical conversion occurring before or after uptake by the tissue.

Chemical conversions occurring after uptake by the tissue result from the interaction of the biocide with the metabolic pathways within the tissue cells. This process is generally referred to as "biotransformation," since it takes place at the cellular level. Such conversions

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* Uropygial gland - A large gland that opens on the back at the base of the tail feathers in most birds and secretes an oily fluid which the bird uses in preening its feathers. Especially developed in waterfowl to help make the plummage shed water. Also called the "preen gland."

may drastically alter the solubility, storage potential and other characteristics of the parent compound, thereby affecting its potential toxicity as well (Stickel, 1973). Biotransformation may, however, also occur prior to the uptake of the chemical by a bird. In this situation, micro-organisms (e.g., bacteria, fungi), plants or animals that the bird feeds on or is in contact with can often transform the parent compound. Consequently, when the chemical enters the bird it is already transformed. For example, Tonomura *et al.*, (1972) reported that mercurial compounds (e.g., organomercurial pesticides) can be converted to the toxic alkyl and inorganic mercury forms by soil bacteria. These chemical forms may then accumulate in soil organisms (e.g., worms, insects, etc.) and vegetation and subsequently be ingested by bird species utilizing these food sources.

4.2.1 External Tissues

Bearing the foregoing in mind, external tissues such as the skin have been found to absorb and accumulate biocides, the amount taken up generally increasing as biocide exposure levels increase (Herrick *et al.*, 1969; Stickel, 1966, 1968, 1973; Schlinke, 1970; Thomas and Medley, 1971; Fowle, 1972; Kenaga, 1974). In experiments where doses of phosphamidon were applied to the bare skin under the wings and breasts of wild songbirds (Fowle, 1972) it was found that the birds could absorb sufficient quantities of the biocide to elicit symptoms of poisoning that often resulted in death. Similar experiments with chlorpyrifos* dusting of 12- and 20-week old white turkeys produced equivalent results (Schlinke, 1970).

Fowle (1965, 1972) demonstrated that the feet of birds are also permeable to biocides. Songbirds exposed to perches treated with phosphamidon displayed typical symptoms of poisoning that often resulted in death of the test bird. Fowle interestingly noted that doses applied to the bare skin under the wing or breast killed birds more rapidly than equivalent doses applied to the feet. The reason for this was unclear though.

As previously mentioned, feathers are also an important potential source of biocide uptake. Kenaga (1974), for example, found that sifting 25 percent chlorphyrifos dust into the feathers of turkeys caused death. In this case, as in most others, ingestion via preening

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* The active ingredient of DURSBAN and LORSBAN, chemicals that are often used in mosquito-control programs.

activities appears to be the mode of biocide uptake from the feather surface.

Other external tissues such as the eyes do not appear to have received much research attention other than in chemical registration experiments, and, therefore, the susceptibility of these tissues to biocide uptake in the natural environment remains unclear.

Whenever a bird is exposed to biocide contaminated surfaces, then the probability is high that a degree of dermal uptake will occur. Evidence supporting this finding is now quite substantial.

The total amount of a biocide or its metabolite(s) present in a given external tissue at any given time consequently depends upon several factors including the species of bird (since some species accumulate biocides more readily than others - Brooks, 1972), the exposure dosage, the rate of uptake and accumulation, the biological half-life of the chemical, the physiological condition of the bird and the level of metabolic activity of the tissue (Stickel, 1973). Of these, the metabolic rate and physiological condition of the bird have a marked effect on the potential toxicity of a given biocide. This point is dealt with in more detail later, but generally, larger species have lower metabolic rates than smaller ones and consequently ingest less food in proportion to their body size (Whittow, 1965; Hill, 1971). This means that the amount of biocide initially taken up by a given tissue is likely to be less per unit body weight, thereby creating less of a toxicity hazard in larger birds than in smaller ones. (One must not, however, exclude the potential toxicity of these lower dosages over a prolonged period of time.) This, of course, assumes that the bird is not under any physiological stress such as would arise during periods of starvation, disease, moulting, etc. In these cases, the degree of biocide accumulation and mobilization by the tissues can be correlated to the nature and degree of physiological stress (Stickel, 1974).

4.2.2 Internal Tissues

Internal tissues such as the liver, kidneys, brain, muscles, nervous ststem, digestive system, heart, fat, eggs, etc., are generally exposed to biocides as a direct or indirect consequence of the ingestion of biocide-contaminated food. Thus, biocides entering the stomach and digestive tract may be absorbed into the blood stream and distributed to all parts of the body leading to uptake and accumulation in almost all tissues.

Accumulation by internal tissues has been demonstrated as early as 1947 by Rubin *et al.*, to be proportional to the dose exposed to. These early investigations found that hens fed diets containing DDT accumulated increasing amounts of DDT in their tissues and eggs, with increasing dietary dosages. Since that time numerous studies have confirmed this observation with other biocides, even in the tissues of wild birds (Edwards, 1970; Stickel, 1973; Medley, 1974; Woodham *et al.*, 1975). An example of the latter can be obtained from birds that eat other birds or fish, i.e., birds of prey (e.g., herons, grebes, bald eagles, falcons, cormorants, pelicans, ospreys, etc.) These birds tend to have higher residue levels than those that eat seeds or vegetation. This results from the increasing accumulation of biocide residues at each successive step along food chains in the ecosystem (Cramp *et al.*, 1964; Miller, 1975; Peakall, 1975a; Cloud, 1975) - see figure 2.

Of the tissues investigated in the body, one of the most commonly monitored for residue accumulation is fat tissue. Stickel (1973) notes that the persistent organochlorine pesticides accumulate in the fat of birds even after a relatively low exposure. Thus, DDE, a primary breakdown product of DDT, has been found to be universally distributed in birds, so that few, if any, wild birds are free from this compound. The parent compound DDT is present less frequently and so is DDD, another DDT metabolite that has been used as a pesticide. Other common fat-soluble organochlorines found to accumulate are dieldrin, heptachlor epoxide, chlordane, lindane and endrin. The accumulation of these compounds, however, occurs at different rates, i.e., heptachlor epoxide$\gg$ dieldrin$>$endrin$>$DDT$>$ lindane - Cummings (1966, 1967) - with one chemical often enhancing the storage of another (Richey *et al.*, 1967). Fat-soluble organophosphorous pesticides, on the other hand, are generally transformed into water soluble metabolites with relative ease in the avian body and are rapidly excreted in bile and feces (Eto, 1974).

The preceding observations are important when considering the uptake and accumulation of biocides by a given bird species in a particular geographic locale since the types and pattern of biocide usage in an area might be expected to be reflected in the residues observed in bird tissues. Probably not all fat-soluble metabolites of the numerous chemicals known to accumulate in fat have been identified due to the unavailability of adequate analytical procedures or apparatus. For this reason, it is expected that the identification of new biocide contaminants will continue, especially as new analytical techniques are developed. Some research along these lines is presently being performed by the Provincial Department of Agriculture.

Bird eggs are also commonly monitored for biocide residues since residues in eggs reflect tissue concentrations at a specific time of the annual cycle. In addition, egg residue concentrations also provide a very useful index of the degree of exposure of the embryo to biocides, thereby providing valuable information that can then be correlated with observed teratogenic effects. In fact, one of the major tests of a particular biocide's potential toxic effects involves the injection of varying doses of biocide into fresh eggs followed by analysis for various metabolic or morphological abnormalities. Perhaps more important, bird eggs provide a useful means for the comparison of various bird species within and from different geographical areas for the influence of biocides on such population parameters as egg fertility and hatchibility as well as survival and mortality of hatchlings.

Numerous studies performed in Great Britian, the United States and Canada have now clearly demonstrated that biocide residues may enter and accumulate in the eggs of both domestic and wild species through either the normal reproductive process within the female or through contact with a biocide as the egg lies in its nest. In the first case, biocides can be transmitted to the developing egg within the female ovary. Here the young egg is in close association with blood vessels that supply it with numerous essential nutrients required for normal development. Entering with or as part of these nutrients are biocide residues (Sturkie, 1965; Welty, 1966; Stickel, 1973). To study this phenomenon investigators generally submit experimental birds to varying biocide doses within their diets and observe the uptake, accumulation and metabolism of the chemical. For example, Davison *et al.*, (1975) fed laying white leghorn chickens and Japanese quail increasing concentrations of mirex* for 12 weeks and found residue accumulation within the eggs was proportional to the dietary dose. These results generally typify the observations of numerous researchers who have undertaken similar experiments using different test bird species and biocides. It is interesting to note that the residue concentrations observed in the eggs of different groups of birds varies with their dietary source. Birds that eat other birds or fish usually have higher residues in their eggs than those that eat seeds and vegetation (Stickel, 1973). The eggs of freshwater fish-eaters such as herons and grebes have been found to contain residue concentrations ten times greater than those of seabirds (Moore and Tatton, 1965).

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* Mirex - An unusually persistent organochlorine insecticide used in Southern United States for fire-ant control.

In the second case, some researchers have found that biocides contacting the egg in its nest can result in entry of the chemical into the egg. Somers *et al.*, (1974 a,b), for example, found that picloram and 2,4-D when applied to the surface of fertile hens' eggs showed entry into the internal contents. No adverse effects resulted, however, with respect to either incubation or subsequent performance of the live chicks. In fact, concentrations twenty times the average application failed to provoke any pre- or post-embryonic problems. In the natural environment, therefore, this mode of biocide uptake probably makes a relatively minor contribution to the total residue concentrations recorded for eggs.

Results similar to those obtained for fat tissue and eggs have consistently been obtained for almost all other bird tissues that have been investigated (see Stickel, 1973, and Peakall, 1975a for more detailed discussion). Consequently, ample evidence exists to clearly demonstrate that biocides can and are accumulated in the living tissues of birds.

5. Response of Birds to Biocide Exposure

5. RESPONSE OF BIRDS TO BIOCIDE EXPOSURE

From the preceeding section, it should now be clear that biocides present a hazard to birds in that they may be taken up by and accumulated in bird tissues for considerable lengths of time. The next question arising concerns the effects of these chemicals on the bird. A survey of the literature reveals that biocide residues in birds may be directly harmful by causing their death (i.e., lethal effects) or they may harm birds in other less conspicuous and often undetectable ways that do not produce mortality as an end result (i.e.,sublethal effects).

In assessing the degree of hazard to birds associated with any biocide it is first important to secure and consider information outlining the physical and chemical properties of the biocide. This information helps focus the researcher on the more probable sites within the body where the chemical is likely to exert its effects. It may also provide clues for the cause of the effect. For example, fat-soluble biocides are commonly analyzed in the fat tissues and have led researchers to study areas such as lethal mobilization following conditions of starvation or disease (Stickel, 1973).

Evidence for or against deleterious effects essentially comes from three sources:

1. Comparison of the levels of biocides in the tissues of dead birds with the levels found in experimentally poisoned birds.

2. Extrapolation of the effects of biocides on laboratory poisoned birds to birds in their natural setting.

3. Studies of bird population changes in relation to the pattern of biocide usage.

It has frequently been assumed that when dead birds are found to contain biocide residues, the biocide must have caused their deaths. It has also been concluded that birds fed diets containing biocides or otherwise exposed directly to biocides (e.g., injection) exhibit responses directly attributable to the biocides. Alternatively, decline in the numbers of certain species of birds has been correlated to the usage of biocides. Such conclusions have repeatedly been criticized as circumstantial evidence since the diagnosis of the cause of these effects is difficult for many reasons, including variation due to the kind and amount of chemical the bird is exposed to, the species and size of the bird,

their physiological condition, age, sex and numerous extraneous factors. Although the degree of validity varies for conclusions based upon these assumptions, it is now generally recognized that conclusive proof is necessary in establishing the cause of deleterious effects of biocides on birds.

Previously, analytical techniques and experimental designs were often imperfect both in terms of accuracy and the delineation of proper standards. This has often led to erroneous conclusions which still persist. In recent years, however, the trend has been toward the development and use of more accurate, standardized techniques by which more data on biocide effects can be compared. In this regard, Stickel (1968) has recognized three types of research effort as being necessary:

1. Research to establish the toxic limits and sublethal effects of biocides and the variations in these effects due to physiological and environmental stresses.

2. Research to monitor the quantities of biocides in the environment, particularly in environments of species that are declining in numbers.

3. Research to establish the rates and routes of gain and loss in and among various living and non-living components of the ecosystem.

With the increase in the number of chemicals being formulated for biocide use, these lines of research can be expected to become even more important in the future. It is already clear though that valuable information pertaining to the response of birds to biocide exposure is being accumulated at a rapid rate.

Below, a few examples are considered to elaborate on some of the more common responses already identified.

5.1 METHODS OF EVALUATING THE RESPONSE OF BIRDS TO BIOCIDES

Before the consequences of the exposure of birds to biocides can have meaning, it is important to understand some of the parameters by which these responses are identified, measured and classified. Some of the more common studies undertaken to obtain data concerning biocide effects are :

1. Acute oral toxicity (LD_{50})*
2. Subacute and chronic oral toxicity
3. Acute exposure (e.g. skin, eyes, feet; LC_{50}, LC_{95})
4. Subacute and chronic exposure
5. Tissue metabolism (uptake, storage, degradation rates of a biocide and/or its metabolites *in vitro* or *in vivo*).
6. Neurotoxicity (e.g., acetylcholinesterase levels - related to transmissibility of nerve impulses)
7. Reproduction (e.g., eggshell thickness, hatchibility, fertility, enzyme and hormone levels)
8. Teratogenicity (i.e., production of abnormal offspring)
9. Tumorigenicity (i.e., production of tumors)
10. Mutagenicity (i.e., production of genetic changes)
11. Enzyme induction (i.e., enzyme - stimulating effects of biocides)
12. Synergistic effects (i.e., potential of one compound to affect the storage and effects of another)
13. Behavioral (e.g., direct observations of behavioral patterns)
14. Population changes (e.g., nesting mortality; susceptibility to predation, disease)
15. Interactions of any of the above.

The preceeding list cannot be considered complete in view of new methodologies that are rapidly being developed; however, it does outline the most common types of research conducted to establish the effects of biocides.

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* See glossary for explanation of terms.

5.2 INTERNAL RESPONSES

The effect(s) a particular biocide exerts on a given tissue is dependent on several factors, including the kind of chemical (i.e., its physical and chemical properties), the species, sex and age of the bird, the kind of tissue, the degree of toxication of the bird, its physiological condition and the rates of uptake, accumulation and degradation of the chemical and/or its metabolites. Generally, the response of the bird is classified as sublethal or lethal.

Sublethal responses are those that do not lead to the immediate death of the bird. In these cases, the tissues of the bird accumulate biocide residues at levels that are not high enough to kill the bird outright. This does not mean though that the bird is completely unaffected by their presence. On the contrary, numberous effects are possible and have been repeatedly observed in both domestic and wild species. One of the more common observations, for example, is the stimulating or depressing effect biocide residues exert on the hormonal and enzymatic activities within various tissues. Organochlorine residues, for example, have been found to induce higher activities of certain liver enzymes which subsequently increase steroid* metabolism, thereby causing a temporary reduction in circulating steroid levels (Ostreicher *et al.*, 1971; Peakall, 1967, 1975b; Britton, 1975). This can produce delayed breeding if normal steroid levels are not restored.

Enzyme activities can also be reduced in tissues. In the well-known eggshell thinning problem, for example, organochlorine residues (e.g., DDE and other compounds of the DDT group) have been linked to the reduction in activity of carbonic anhydrase, the enzyme believed to be responsible for supplying carbonate ions for calcium carbonate deposition in the shell gland during eggshell formation (Peakall, 1970; Bitman *et al*, 1970). The overall consequence of this internal response is a decline in population numbers such as occurred for North American peregrine falcons (Peakall *et al*, 1975; Fyfe *et al*, 1969; Cade and Fyfe, 1970). Other biocides such as PCB's appear to have little effect on shell thinning (Cooke, 1973; Peakall, 1975a).

In addition to enzyme level reduction, enzymes may also be inhibited by biocides. The neural enzyme cholinesterase** is very sensitive

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* Steroid - Reproductive hormones e.g., estrogen, oestrodiol.

** Cholinesterase is responsible for degrading the nerve impulse transmitter, acetylcholine, following its activation of the muscle fiber membrane.

to the presence of certain biocide residues in the brain, for example. In this tissue inhibitions of 50 percent has been reported for birds fed diets containing parathion and carbofuran (Ludke *et al.*, 1975). Although organophosphate biocides generally have little residual accumulation, additive effects are possible in the presence of other compounds. In this regard, Dieter and Ludke (1975) found that parathion toxicity increased in the presence of the methylmercury compound, morsodren.

Biocides may also elicit other internal responses. They may affect the hereditary processes of cells by enhancing genetic changes (i.e., mutations) or affect the storage potential of other chemicals in the tissue through synergistic effects (Stickel, 1973). Changes in reproductive processes are also common and may result from delayed ovulation, reduced clutch size, longer incubation and rearing periods, reduced hatchling survival or increased embryo and egg morphological deformities. These are only a few of the numerous ways the internal workings of a bird may respond to sublethal biocide exposure. A complete discussion of all known responses is beyond the scope of this report.

Whatever the response, it is known that birds contaminated by biocide residues continuously deplete their bodies of these residues through their normal metabolic and physiologic processes. This means that factors affecting these processes will play a large part in determining the response of the bird to the biocide. Age of the bird, for example, appears to be an important factor. Although young birds appear to be more susceptible to the effects of biocides than adults (Friend and Trainer, 1974), this may not always hold true. Hudson *et al.*, (1972) found that in experiments where mallard ducks of different ages were exposed to fourteen common pesticides, young ducklings often displayed less susceptibility. The onset of mortality and mean time of death at each dosage level was related to age in a dose-dependent relationship.

Sex can also have an important bearing on the bird-biocide response. Friend and Trainer (1974) found that adult female mallards were more resistant to DDT intoxication than adult males.

In addition to the above, any event that speeds up the mobilization of stored residues (e.g,. starvation, disease, moulting, egg incubation, migration, stress, etc.) may suddenly kill apparently healthy animals long after exposure to the chemical or at dosages that would normally not harm them. This response generally arises in the more susceptible species and individuals of a species first and has been intensively studied in laboratory experiments in which a weight loss was induced in both wild and domestic species after discontinuation of exposure to the chemical (Noakes

and Benfield, 1965; Smith *et al.*, 1970; Soedergren and Ulfstrand, 1972). In these experiments the chemical was initially stored sublethally in the bird's fat tissues, which, under conditions promoting fat utilization, released sufficiently high doses within a short period of time to cause death. This situation is important to bear in mind when attempting to establish the cause of bird death in a particular area. The highly mobile nature of birds means that they can pick up a sublethal biocide dose in one area and move into another. Consequently, should the bird die while in the latter area, the cause of death may actually reflect the effects of sublethal dose mobilization rather than the effects of the biocide(s) being used in that area.

Lethal responses are those that result in the death of the bird shortly after exposure to the biocide. In these cases the level of the chemical is sufficiently high to disrupt the bird's normal physiological processes following uptake by the tissues. It must be remembered here that some tissues are more sensitive to a given biocide dosage than others, and, consequently, respond more rapidly. The brain, for example, is very sensitive to biocide residues and for this reason is considered the most critical tissue to analyse for residues before concluding a biocide residue to be the cause of death. Unfortunately, this is not always possible as in situations where dead wild birds are found as it is in controlled laboratory situations. Other tissues, of course, also act as valuable indicators of regular or recent biocide exposure (e.g., liver). Species variation in tissue sensitivity also occurs. Bailey *et al.*, (1969) and Stickel *et al.* (1969), for example, found higher minimum lethal levels of quail brain tissue to DDE poisoning than of pigeon brains.

The internal response elicited by birds exposed to biocides can, therefore, be diverse and complex. To date a considerable amount of research effort has been expended to more fully comprehend these responses. However, in the future more research will be needed before the full impact of the bird-biocide situation on the ecosystem becomes clear.

5.3 EXTERNAL RESPONSES

Birds exposed to biocides may also elicit external responses. Two of the more common responses are population and behavioral changes, both of which are discussed below.

5.3.1 Population Changes

The effects of biocides on populations have been investigated in some detail, although the research is by no means considered complete.

Results obtained from numerous studies indicate that bird populations generally decline after exposure to biocides. The cause(s) of this decline may be direct or indirect. Since birds may respond quite rapidly to biocides, the most striking examples of direct causes are those that occur when birds are killed outright after application of the biocide, as in the case with DDT used to control Dutch elm disease in the United States in the 1950s. In this instance, birds reportedly died in large numbers immediately after being sprayed by DDT (Stefferud, 1966). Since that time, other instances of sudden population declines have been reported. The appearance of dead and/or incapacitated birds in these situations, however, has too often been concluded as direct evidence for a biocide-induced effect, particularly in urban areas where numerous extraneous factors (e.g. noise, fright, intrusion) can also lead to population declines. Before biocides can be implicated as the causal agents of these declines, population counts should be conducted in treated areas before and after application of a biocide. A good example of such a study conducted within Canada is described by Fowle (1972). Using the spruce budworm insecticide phosphamidon, he demonstrated that population numbers of several wild bird species (e.g,. white-throated sparrows, warblers, ruffed grouse, wrens, thrushes, cowbirds, finches and juncos) in a New Brunswick forest declined following the spraying of phosphamidon. Interestingly enough, he also found that their population numbers recovered to normal following discontinuation of exposure to the chemical. This phenomenon has been documented repeatedly for wild bird populations, although one must bear in mind that it may not always hold true.

Bird populations are also influenced by indirect causes. Included within this category are the previously mentioned delayed ovulation, abnormal and sterile egg formation, eggshell thinning, embryotoxic effects, post-hatching mortality, etc. All of these responses have, at one time or another, been linked to biocides. Delayed ovulation times, for example, have been observed in finches (Jefferies, 1969) and ducks (Peakall, 1970) fed diets contaminated with DDT. Eggshell thinning, on the other hand, is hypothesized to result in population declines because thinning increases the probability of crushing or cracking the egg while in the nest (Longcore and Samson, 1973; Stickel, 1974). A thinning factor of 15 to 20 percent over a period of years is considered to be responsible for reduced hatching success (Anderson and Hickey, 1972). This response has largely been attributed to the organochlorine biocides rather than the PCB's or organophosphates.

In addition to the thinning phenomenon, biocides may also cause the production of soft-shelled, abnormally shaped or sterile

eggs (Pimental, 1972; Egberts *et al.*, 1972; Call and Harrell, 1974) that result in reduced hatches. Embryotoxic effects within the egg also reflect biocide presence. If the concentration of biocide within the egg is high enough, outright death of the embryo can result (Porter and Wiemeyer, 1969). At lower concentrations abnormalities in development can occur (Ammitzboell and Clausen, 1973; Younger, 1973; Carlson and Duby, 1973; Ho and Gibson, 1972). Both responses can reduce the number of eggs successfully hatched.

Post-hatching mortality is yet another major factor causing declines in bird populations. In this case declines may arise through the inability of nestlings to grow and/or function normally. For example, teratogenic effects such as wing or beak deformities may result in death through the bird's inability to fly or feed itself. These factors, at the same time, increase the birds' susceptibility to predators. Lower reproductive success can therefore be manifest in many ways.

A final indirect external response is related to the birds' food supply. Birds feeding on insects will inadvertently be affected by insecticide use since these chemicals will eliminate or reduce their food source. This pressure alone can lead to reduced population numbers through starvation. Such an event could then lead to declines in predatory birds that feed on insectivorous birds. External responses of bird populations to biocides are, therefore, diversified and complex and are intimately associated with internal responses. Both types of response can lead to insufficient numbers to maintain a stable population.

5.3.2 Behavioral Changes

The normal behavioral patterns of birds have often been reported to be altered by biocides. Fowle (1972) reported that sublethal doses of the insecticide phosphamidon (0.125 to 0.500 lb./acre) caused a variety of behavioural responses in birds in a treated forested area in New Brunswick. The responses of free and caged wild birds included trembling, tail vibrating, wing drooping, shaking of the head, constant wiping of the bill on perches, reduced singing, abnormal eye blinking or closing, inability to maintain a proper stance, stumbling gait, convulsions, lethargy or complete incapacitation. The frequent occurrence of similar symptoms in numerous other cases of bird poisoning is substantial evidence to indicate that bird behaviour can be altered upon exposure to biocides. The response elicited appears to be related to such factors as species of bird, age, sex, time since last feeding, type and dosage of chemical exposed to, etc.

The chemical(s) that the bird is exposed to is an important consideration since not all biocides noticeably affect bird behaviour. Malathion and chlorpyrifos*, for example, have been shown to have little, if any, behavioural effects on birds and are reportedly safe for use in the environment (Giles, 1970; Bejer-Petersen *et al.*, 1972; Kenaga, 1974). It has been that the more persistent DDT, on the other hand, may, over a long period of time, induce deliberate egg breaking or eating in adult peregrine falcons (Ratcliffe, 1970). This suggestion, although tenuous, gains some support from Milstein's *et al.*, (1970) observation of grey heron stabbing and expulsion of eggs in the nest. The reproducibility of these observations in other avian species, however, requires further study.

Other behavioural changes may become apparent in birds. Botterweg *et al.*, (1972) found nervousness in Kestrels increased after exposure to the fungicide hexachlorobenzene. Kreitzer and Heinz (1974) found that the avoidance response in young quail was suppressed by sublethal doses of chlordane, dieldrin, endrin and the PCB, Aroclor 1254. DDE, however, failed to produce any aberrant behaviour. Heinz (1975), on the other hand, observed a dramatic increase in avoidance of methyl mercury-fed mallard ducklings to a frightening stimulus. These results should illustrate the diversity in behavioural changes that can arise in different species exposed to different biocides at different biocide dosages. In regard to the latter, Lewis *et al.*, (1973) demonstrated that pigeons fed phosdrin (mevinphos), a cholinesterase-inhibiting pesticide, exhibited a decrease in response rate that was dose-related. This finding, of course, may not hold for all birds and should be examined in more detail, particularly at doses below which external symptoms of biocide poisoning are apparent. It is interesting to note that bird behaviour can, in some cases, return to normal following discontinuation of exposure to biocides (Schafer, 1972; Kreitzer and Heinz, 1975).

In assessing the effects of biocides on birds then it is important to consider both the internal and external responses elicited by these chemicals as well as the interaction between the two types of response.

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* Chlorpyrifos, however, was tested by the U.S. Fish and Wildlife Service for potential use in bird control situations since at high enough concentration (1,000 - 10,000 ppm), it acts as a sleep-inducing agent (Schafer, 1972).

6. Mosquito Abatement and Birds

6. THE MOSQUITO ABATEMENT PROBLEM

In Man's continual efforts against insects, one of the most persistent problems is that related to mosquito control. Besides being bothersome to humans, animals and birds, mosquitos can also create health hazards, causing diseases such as equine encephalitis, yellow fever, filariosis and malaria. Consequently, as our society engages in more outdoor activities, the desire for a mosquito-free environment increases.

Although many chemicals are available that will provide excellent control for mosquitos, the foremost problem remaining is that of choosing a chemical that will provide minimal damage to other organisms. With the present awareness of the problems created for birds by pesticides, it seems logical to only recommend those materials for mosquito control that are toxicologically safe to non-target species such as birds. The only justifiable exceptions would be cases of emergency where the health of a community must be safeguarded.

To control mosquitos, pesticides have been applied to act against mosquito larvae (i.e., larvicides) or adults (i.e., adulticides). The most common chemicals used have been methoxychlor, Abate, Dursban, Vapona, Baytex and Malathion. The form in which these chemicals are applied varies with the situation, but larvicides are now generally applied as granular formations rather than oil solutions or emulsion concentrates, since granules penetrate vegetation better and reduce the hazards related to drift and contamination of livestock and wildlife. Adulticides, on the other hand, are generally applied in liquid form by aerial or ground methods such as ultra low volume or mist spraying and thermal or cold fogging.

The effect a mosquito-control formulation has on birds, then, will depend on numerous factors including the kind of chemical (i.e., physical and chemical properties), the dosage applied, the form in which it is applied, (e.g., granules, oil solution, emulsion, the manner in which it is applied (e.g., aerial or ground), as well as the numerous factors previously mentioned governing the uptake and metabolism of the chemical by the bird.

6.1 Chemical Used

The chemical used for mosquito control is an important factor to consider when assessing the potential hazard to birds. Abate, for example, although classified as highly effective against many different

species of mosquito larvae, has been found to be highly toxic to perching birds such as blue jays, house sparrows and cardinals and moderately toxic to game birds such as mallards, pheasants and partridges (Hill, 1971). The differential toxicity observed among the various species tested indicated the larger species to be more tolerant than the smaller ones, presumably because the larger species have lower metabolic rates and food intakes in proportion to their size than the smaller birds (Whittow, 1965). Dursban, whose active ingredient is chlorpyrifos, has been shown to accumulate sublethally in the skin and fat of birds (Claborn *et al.*, 1970; Schlinke, 1970; Dishburger *et al.*, 1972) and has also been demonstrated to possess sleep-inducing properties that make it potentially useful as a bird repellant for pest bird control (Schafer, 1972). Yet the toxicological effects of this chemical, at the same time, have not been found to be significant and, therefore, it is considered safe for mosquito control programs (Kenaga, 1974). Vapona has similarly been classified as possessing low toxicity for birds (Travis *et al.*, 1968). Methoxychlor, the only organochlorine recommended for mosquito control, has little cumulative capacity in birds, disappears from the tissues rapidly after dosage ceases and has little potential transfer to eggs (Olney *et al.*, 1962; Thompson *et al.*, 1967; Mueller and Leach, 1974; Stickel, 1973). The transient nature of this compound in the tissues of wild birds has been clearly demonstrated in numerous field applications. For example, Hunt and Sacho (1969) demonstrated that methoxychlor applied at a rate of 10 lbs/acre to control Dutch elm disease resulted in the recovery of methoxychlor residues from soils and worms in the area, but not from birds. Methoxychlor, even when used as a poultry insect-control powder produced no detectable residues, even at the highest level tested of 2,000 ppm (Herrick *et al.*, 1969). Since no serious toxic effects have been reported, it appears that methoxychlor presents little hazard to birds.

Of the chemicals used for mosquito control, malathion, which includes Cythion, currently appears to be the safest for birds based on numerous studies performed by industry, government and universities. At moderate rates of application malathion does not detectably affect birds, is short-lived in the environment and has little cumulative capacity in soil, plants and invertebrates (Giles, 1970). This does not mean that toxicological effects are completely absent for this chemical. On the contrary, numerous investigations have demonstrated adverse affects of varying severity in some bird species. For example, malathion injected into hens' eggs produced a high percentage of embryo deaths as well as teratogenic effects (Pimentel, 1971). In addition, weight loss and fat tissue residue accumulation have been observed (Cecil *et al.*, 1974). Malathion is also a member of the cholinesterase-inhibiting class of pesticides (Mitchell and Ynetema, 1973)

but it is far less effective than any other members of this class (e.g., fenthion, parathion). As with all cholinesterase inhibitors, excessive absorption of the compound into the body causes a reduction in cholinesterase activity in the blood and nerve tissues that may progress to the point at which symptoms of intense para-sympathetic stimulation appear (e.g. decreased heart rate, lung constriction, increased gastrointestinal secretion). If the source of contamination is removed, the attack is generally of short duration and recovery is usually rapid and complete within several hours.

Within Edmonton, the Department of the Environment monitored the populations of fifteen species of game and non-game birds exposed to ultra low volume (ULV) aerial and ground applications of malathion in 1971 and 1973 and recorded no detectable adverse affects in adult or immature bird populations. The City of Edmonton, in co-operation with the Department of the Environment, performed a similar survey in the summer of 1974, the results substantiating the previous findings of the D.O.E. In spite of this evidence in favour of malathion, a few isolated reports over the past few years have attributed the decline of purple martins and tree swallows in Edmonton to the use of this chemical (Allan, 1975). Since no post-mortem residue analyses were performed in these cases, the cause of the apparent population declines is still not precisely known.

Within Alberta, then, the three most commonly applied pesticides for mosquito control are Abate, Dursban and Malathion. As previously stated, each possesses certain advantages and disadvantages. Since current research results present evidence both supporting and refuting claims of toxicological effects in birds exposed to these chemicals, conclusions regarding justification of their use remain tenuous at best. It is, therefore, desirable that more detailed research be performed on further wild bird species to provide firmer conclusions of the effects of these chemicals. Such research could be undertaken by the City of Edmonton, the Department of the Environment and perhaps personnel at the University of Alberta who are well versed in ornithological and/or toxocological problems.

It is noteworthy at this point that the U.S. Environmental Protection Agency lists chlorpyrifos, malathion, methoxychlor, carbaryl, fenthion, naled, propoxur, pyrethrins and resethrins as safe for use against adult mosquitos *(Canadian Environmental Newsletter,* 1975).

6.2 DOSAGE APPLIED

As previously stated, the amount of pesticide taken up by birds and their subsequent response is generally proportional to the exposure dosage. For this reason, the amount of pesticide applied in an area should be maintained at the lowest possible level to ensure adequate mosquito control while presenting the lowest possible hazard to wildlife. Furthermore, chemical application should be undertaken only when necessary and in areas requiring it, using techniques that ensure application of the proper dosage. Not only will these steps reduce the dosage of chemical birds are exposed to but also the numbers of birds exposed to the particular dosage.

Current mosquito-control practices appear to be striving towards these ends. For example, granulated Dursban used in larviciding programs usually ranges from 1 to 5 percent in strength. Future mosquito-control programs will, it is hoped, adopt this philosophy and strive to reduce the hazard of the chemicals to non-target species.

6.3 FORM OF CHEMICAL APPLICATION

The form in which a mosquito-control pesticide is applied may also affect birds. The granular form, for example, has created some concern over the possible deliberate or accidental ingestion of chemical-laden granules by birds. Although this possibility does exist, three things must be borne in mind when assessing this hazard:

1) At the chemical concentration of the granules (e.g., 2 percent) a bird would have to ingest a large number of granules before the exposure dosage was sufficiently high to be harmful to the bird.

2) Birds (e.g., house sparrows, common gackles and red-winged blackbirds) have been reported to be repelled by food sources contaminated with pesticides (Schafer, 1972).

3) The chemicals used are generally short-lived and do not have a significant cumulative capacity in bird tissues to present a serious hazard.

Chemicals have also been applied as an oil solution in which a carrier such as diesel fuel has been used to promote settling of the chemical. This method, however, is less popular since oil residues are left on vegetation, soil and buildings, etc. Consequently, the oil residues may pose a more severe threat to birds than the mosquito control chemical. Further study is needed to clarify this situation.

6.4 METHOD OF APPLICATION

The method by which the control chemical is applied may also affect birds. Aerial application covers large areas and often gives rise to problems related to drift. It, therefore, has the potential of affecting larger numbers of birds. Adult birds may inadvertently be frightened from their nests by the aircraft applying the pesticide. Leaving eggs of nestlings exposed to climatic conditions and/or the chemical could result in higher nest mortality. Ground application, too, can affect large areas (e.g., misting, fogging), exposing large numbers of birds to the chemical. However under controlled application where only small areas or bodies of water are involved, fewer birds are likely to be exposed to the pesticide, thereby reducing the overall hazard.

6.5 BIRD CONTROL OF INSECT POPULATIONS

It is well known that numerous bird species (e.g., martins, swallows, swifts, flycatchers, titmice, nuthatches, woodpeckers, etc.) depend upon insects as their chief source of food. As such, birds have a significant impact on insect populations. In the case of mosquitos, many bird species supplement their diets with these insects, thereby reducing mosquito numbers. The introduction of mosquito-control chemicals into the environment, however, can lead to a disruption of this natural balance and should be carefully controlled. Birds eating mosquitos contaminated by sublethal doses of pesticides can accumulate these chemicals and become exposed to their effects as previously mentioned. Steps should be taken, therefore, to minimize the effects of mosquito-control chemicals on birds and bird populations. In fact, in areas where birds are performing adequately in keeping mosquito numbers to a sufficiently low level, the necessity for using these chemicals should be reviewed with the ultimate goal of decreasing their usage.

7. Bird Nuisances and Chemical Control

7. BIRD NUISANCES AND CHEMICAL CONTROL

7.1 BACKGROUND

Many bird species have become closely associated with Man and his activities. In its simplest form, this association may merely consist of birds using man-made structures for perching, roosting or nesting, but in its extreme form birds may consume his agricultural crops as a source of food or cause other damage. Consequently, a few game and non-game species of bird are justifiably considered to be nuisances.

In Alberta, the major non-game species causing damage are blackbirds, gulls, magpies, pigeons, starlings and English sparrows. These birds may cause significant agricultural or other losses. Blackbirds, for example, are increasing in significance as a source of damage to corn crops in southern Alberta. Magpies are known to damage livestock by pecking around open wounds caused by warble grubs, dehorning, branding sears or by pecking at the eyes of lambs or calves. English sparrows and gulls are attracted to feedlot operations, consuming and spoiling economically significant amounts of feed grain. Gulls also present an increasing hazard to aircraft around airports. Fouling of buildings, crops and feed occurs, increasing the chances of spreading disease.

Game birds such as ducks, geese and cranes, on the other hand, consume or cause damage to valuable cereal crops such as wheat, oats and barley. In his efforts to control damage caused by birds, Man has conducted considerable research, testing numerous methods of control ranging from live trapping to the use of toxic or aversive chemicals. However, the solutions to these problems are rarely simple and long-lasting since they are compounded by species variations in sensitivity to the control measure as well as the speed at which birds learn and transmit knowledge of new food sources, roosts or techniques of avoiding the very measures designed to control them. It is imperative, therefore, that the desired objective of a specific bird control program (i.e. eradication or repellance) be clearly established prior to the program's initiation. It is also highly desirable that the ecology and habits of the species in question be thoroughly understood in order to achieve optimum control.

7.2 LEGISLATION GOVERNING CHEMICAL CONTROL METHODS

The use of chemicals to control nuisance bird species comes under the jurisdiction of both the federal and provincial governments. Before a chemical may be used in the field, it must first be registered according to the provisions of The Pest Control Products Act (1972) which

requires information pertaining to its physical and chemical properties, its biochemical and toxicological effects on plants, animals and humans, its ecological impact on the physical and biological components of the environment, its proposed uses, formulations, pest and host resistance, etc. This Act is administered by the Control Products Section of the Canada Department of Agriculture.

The provincial Agricultural Chemicals Act (1970), administered by the Department of the Environment, primarily governs the sale, use and application of the chemical in Alberta, ensuring that it meets the registration, packaging and efficacy standards prescribed by federal regulations, as well as the intended purpose for which it is sold or supplied. To this end, a permit or licence, issued by the Pesticide Chemicals Branch, Department of the Environment, is required before the chemical may be applied in field situations (sections 6 and 12).

The Agricultural Pests Act (1974) administered by the Provincial Department of Agriculture stipulates which bird species (excluding birds of prey and game birds as defined in The Wildlife Act, 1970) may be classified as regional or provincial "pests" or "nuisances" (section 2) and the prescribed methods to control these species. It is interesting to note that under this Act, landowners, tenants, stockholders and municipalities have the right to undertake approved steps to control or eradicate "nuisance" bird species but are not legally obliged to do so (section 3), whereas the same parties are legally obliged to eradicate species classified as "pests" on land, premises, livestock, crops or vegetation infested by them or that may contribute to the establishment, maintenance, or spread of the pest (section 4). Destruction of the pest must, however, be undertaken in the manner prescribed in the regulations of this Act, or, where applicable, the regulations of The Wildlife Act or Agricultural Chemicals Act. In Alberta, no bird species have been classified as pests, but the magpie has been declared to be a nuisance throughout the province. Other birds such as English sparrows, pigeons and blackbirds, although not officially declared nuisances, have nevertheless caused considerable damage with control efforts generally being initiated wherever they create a significant problem.

Other Acts that may be related to the use of bird control chemicals are the federal Migratory Birds Convention Act (1970) and the provincial Wildlife Act (1970). In the first case, section 35 may affect the use of chemicals used for bird control since it prohibits the deposition of any substance harmful to migratory birds in any waters or any area frequented by migratory birds unless"... authorized by regulations made by the

Governor-in-Council under any other Act in any waters in respect of which those regulations are appliable". In situations where migratory birds do or are likely to cause damage to property or crops and cannot be deterred by scaring devices (e.g., gulls at airports), a permit issued by the Chief Federal Game Officer of the province with the concurrence of the Director General of the Canadian Wildlife Service, may be issued under sections 25 and 26, permitting the killing of such birds.

Since the method of killing is not clearly specified in these sections, it is conceivable that avicides might be used to achieve control, with, of course, the approval of the regulatory agencies.

Section 24 of The Wildlife Act (1970) also prohibits the use of any poison to kill wildlife except where authorized by The Agricultural Pests Act (1974).

7.3 CHEMICALS USED IN BIRD CONTROL SITUATIONS

A number of chemicals have been manufactured for use in bird control situations as toxicants or repellants. Testing of some of these has been performed in both laboratory and field situations, while for others only in laboratory situations. Consequently, many of the chemicals require further field research before their effects are known, and, therefore, their registration for use within Canada is restricted. Some chemicals that have been applied in field situations have been found to be unsatisfactory from a bird control or ecological standpoint and have subsequently been withdrawn from use.

The following chemicals have been manufactured for controlling birds:

DRC-1339

This oral toxicant has been tested by the U.S. Bureau of Sport Fisheries and Wildlife and is reported to be highly specific to starlings and blackbirds. It has very limited urban utility since sparrows and pigeons are relatively resistant to it. Birds exposed to lethal doses may die over a period of three days and can be widely scattered. The chemical requires stringent measures against human skin contact. It is not registered for field application in Canada and has not been used in Alberta.

Queletox

Queletox (or fenthion as it is also called) is a contact poison manufactured by the Chemagro Corporation. Treatment of perches, nesting areas and roosts reduces pigeon, starling and English sparrow populations. It may also be applied as a 12 percent paste or to cotton cords in roosting and nesting areas. Starlings and sparrows may be repelled by the paste deposits as well. Since extreme care must be exerted when handling this chemical, it has had limited application in urban areas. Further testing in this regard is still needed.

Within Alberta, Queletox has received little attention and is not registered for use in bird control situations.

Endrin

Endrin has been used for nuisance bird control and is administered through a wide-feed perching device. An example is the Bird-X- Perches. Endrin is highly toxic and non-selective to a wide spectrum of birds and animals. The compound is absorbed through the feet of any bird which uses the perch and its action is relatively rapid. This compound is not available for public use for control of nuisance birds in Alberta.

Coumpaphos (Co-Ral)

Coumpaphos, an insecticide powder, has been reported to be effective as a bird repellant when sprayed on small grain plots (Austenson, 1968). Coumpaphos is registered in Canada for use as a direct spray on cattle for warble grub control, as well as on sheep, swine and poultry. The compound has no apparent deleterious effects on plants, bird or mammals and has been used in Alberta for a number of years. Further testing of its bird repellant qualities in urban areas is needed.

Methiocarb (Mesurol)

Methiocarb, a carbamate compound, has been used as a repellant in some bird control situations in the U.S.A. It is a vomit-inducing compound that causes severe alarm reactions in birds ingesting it. Although it has been established as an effective control measure under laboratory and field conditions in the United States, it has not been endorsed in Alberta. As with many of the other chemicals, further field testing is required.

Avitrol

Avitrol (4-aminopyridine) is a bird-alarming repellant-avicide being promoted in Canada by Abell-Waco (representing Avitrol Corporation, U.S.A.) and is registered under The Pest Control Products Act as Avitrol Corn Shops, Avitrol Whole Corn, Avitrol Mixed Grains and Avitrol Concentrate (i.e., 100 and 200 formulations). These products are presently restricted in Alberta and have been registered on a temporary experimental basis (with Canadian BioScientific Consultants Ltd., Edmonton) pending additional data for use in urban-industrial areas by or under the supervision of government agencies or pest control operators.

Avitrol is registered for controlling red-winged blackbirds, Brewer's cowbirds, English sparrows, pigeons, and gulls. It works by causing severe alarm reactions of a few birds in large flocks. The affected birds generally flop around or fly in erratic circles, crying in distress. This behaviour, in turn, scares off the rest of the flock.

Although Avitrol was initially thought to be non-toxic to target and non-target species, recent results from the Ontario Ministry of the Environment reveal that the product often causes many of the affected birds to die in great agony. Furthermore, since the product attacks the central nervous system, it may also affect other non-target birds and even mammals *(ECO/LOG Week,* 1975).

In addition to its toxic effects, the effectiveness of Avitrol in controlling nuisance birds has received some criticism since the compound is not equally effective in controlling all bird species. It may also merely drive the nuisance birds into adjacent, untreated areas, thereby transferring the problem without solving it.

Strychnine

In some bird pest situations strychnine has been used to achieve population control. In Alberta, under The Agricultural Pests Act (1974), strychnine compounds are approved poisons for use in baits for destroying magpies which have recently been declared a "nuisance" species.

Strychnine powder is supplied in a sulfate or alkaloid form with the latter being more effective. Generally, 90 to 99 percent alkaloidal strychnine powder is mixed with hamburger or fat and

set out during the months of November to March. Although strychnine baits are to a large degree distributed, set out and supervised by pest control officers appointed under The Agricultural Pests Act, the baits may also be set out by "..a person who is on his own land or on land or premises occupied and controlled by him..." This person must, of course, follow specific magpie control regulations (Alberta Regulation 72/75).

In Alberta the use of strychnine to control magpies has met with varied success. This has led members of both government and private sectors to experiment with other methods of control. The circular trap is now becoming the most favoured method of magpie control. The use of strychnine also possesses some disadvantates, the primary one being the death of non-target organisms. It is not known, for example, how many other over-wintering bird species (e.g., hairy and downy woodpeckers, chickadees, etc.) die from feeding on magpie baits or strychnine-containing magpie carcasses. Because of this, the necessity for exploring other control devices seems imperative. The provincial Departments of the Environment and Agriculture are presently engaged in legislation to restrict the sales and distribution of this compound.

8. Conclusions

8. CONCLUSIONS

From the foregoing it should now be clear that when Man undertakes to control insect populations through the use of chemical applications, the effects he generates for non-target organisms such as birds may range from minimal to quite severe. It is, therefore, essential that our society realize the implications of using biocides before these chemicals are indiscriminantly distributed throughout the environment.

Although some progress has been made in this regard in the past few years, it is hopeful that all levels of government, industry and the private sector will strive for a more thorough understanding of the effects that biocides exert, not only on birds but also on other forms of wildlife as well as on Man himself.

In its recent Report and Recommendations on The Use of Herbicides and Pesticides in Alberta (February, 1976), the Environment Conservation Authority made several recommendations regarding "accidental avicides." These have been reiterated below to emphasize the importance of solving biocide-bird problems in our environment:

RECOMMENDATIONS

1. That the protection of bird life be accepted as an operating restraint upon insect abatement programs in urban areas and their environments.

2. That increased populations of favoured bird species be encouraged in urban parks and areas by the introduction of feeding stations, bird houses, etc., so as to help control insect populations and diminish the need for hazardous sprays.

3. That studies be undertaken to determine the effect of accidental avicides and of pesticide application procedures on bird life and populations.

4. That the use of persistent chlorinated hydrocarbon pesticides for insect control in urban areas be avoided.

5. That the use of aerial spraying for insect control in urban areas be restricted to special cases to avoid the double danger of accidental damage to birds and the fright producing effect of low-flying aircraft.

6. That pesticides, potentially harmful to birds, be localized by all possible means since pesticides accumulate in birds at a rate proportional to the amount present in a given area.

7. That chemical seed dressings, that could produce adverse effects in birds, not be used in areas where seed-eating birds are predominent or at times when seed-eaters are abundant such as during spring and fall migrations.

8. That programs for monitoring the uptake and residues of pesticides in avian species indigenous to a sprayed area, be established by the Department of Environment in co-operation with the Department of Agriculture.

9. That when an urban area has to be sprayed with insecticide, as in the case of mosquito control, it be monitored for bird activity and population before and after spraying to determine whether detrimetal effects have resulted.

10. That insecticides not be applied in granulated forms since birds may eat granules, thereby ingesting high concentrations of the pesticide.

11. That avicides not be available to the general public but their use restricted to licensed applicators and a permit to use issued for each specific instance.

12. That the public be encouraged to report incidents of bird mortality thought to be related to pesticide or avicide use.

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